Proton Driver Status

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Proton Driver Physics Workshop

Oct 6, 2004

Outline

- **Fermilab Long Range Plan**
  - Linear Collider and Proton Driver recommendations
  - PD Working Group Considerations
  - Proton Driver studies (Synchrotron, SCRF LINAC)
- **Charge to Proton Driver Leadership**
- **Recent Developments**
  - R&D funding
  - ITRP recommendation vs PD
- **Timescale**
  - DOE approval process
  - Technically limited schedule vs funding limited schedule
- **Conclusions**

Fermilab: Long Range Plan

- **The Fermilab Director established the Fermilab Long Range Planning Committee (FLRPC) in the spring of 2003.**
- **Excerpt from the charge to the LRP committee:**
  - " I would like the Long-range Planning Committee to develop in detail a few realistically achievable options for the Fermilab program in the next decade under each possible outcome for the linear collider. …."
- **It was clear from the start that a new intense proton source to serve long baseline neutrino experiments and to provide other new physics options at Fermilab was one such option…**
- A FLRPC working group was charged to explore this option. (RDK chairman) We made recommendations to the full LRP committee that were subsequently adopted in the final FLRPC report

The Fermilab Long Range Plan

- **The committee report is available at:**
  http://www.fnal.gov/directorate/Longrange/Long_range_planning.html
- **The vision expressed in that report is that Fermilab will remain the primary site for accelerator-based particle physics in the U.S. in the next decade and beyond.**
  - As host to a linear collider Fermilab would be established as a world center for the physics of the energy frontier for decades.
  - If the linear collider is constructed elsewhere, or delayed, Fermilab would strive to become a world center of excellence in neutrino physics, based on a (SClinac) multi-MW "Proton Driver", still with significant LC participation.

Fermilab is pursuing linear collider and proton driver R&D in parallel.
The cold decision allows close alignment of these paths.

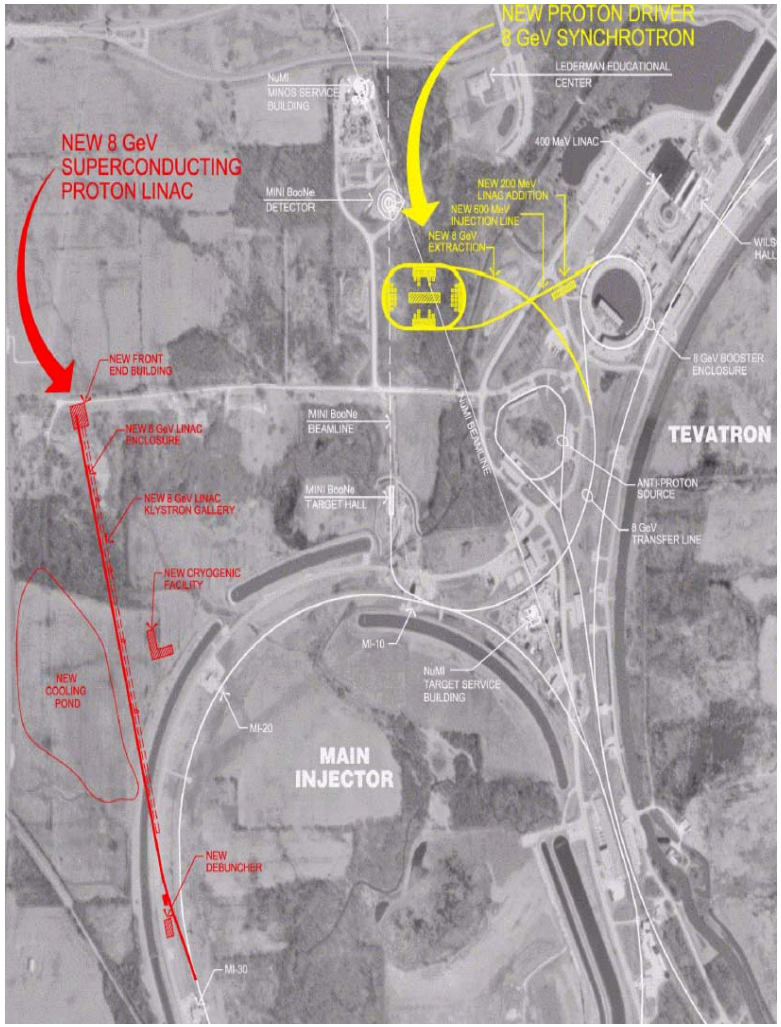
PD Working Group:

Reviewed PD Physics Case and Various Studies of the FNAL Proton Source

- **Several studies have had the goal of understanding the limitations of the existing source and suggesting upgrades**
- **Proton Driver Design Study I:**
  - 16 GeV Synchrotron (TM 2136) Dec 2000
- **Proton Driver Design Study II (draft TM 2169) :**
  - ✔ 8 GeV Synchrotron May 2002
  - ✔ 2 MW upgrade to Main Injector May 2002
  - ✔ 8 GeV Superconducting Linac: Feb 2004
- **Proton Team Report (D Finley):** Oct 2003
  - **Report:** http://www.fnal.gov/directorate/program_planning/studies/ProtonReport.pdf
  - **Limitations of existing source, upgrades for a few 10's of $ M.**
  - "On the longer term the proton demands of the neutrino program will exceed what reasonable upgrades of the present Booster and Linac can accommodate ➔FNAL needs a plan to replace its aging LINAC & Booster with a new more intense proton source (AKA a Proton Driver)

Proton Driver Studies

http://www-bd.fnal.gov/pdriver/

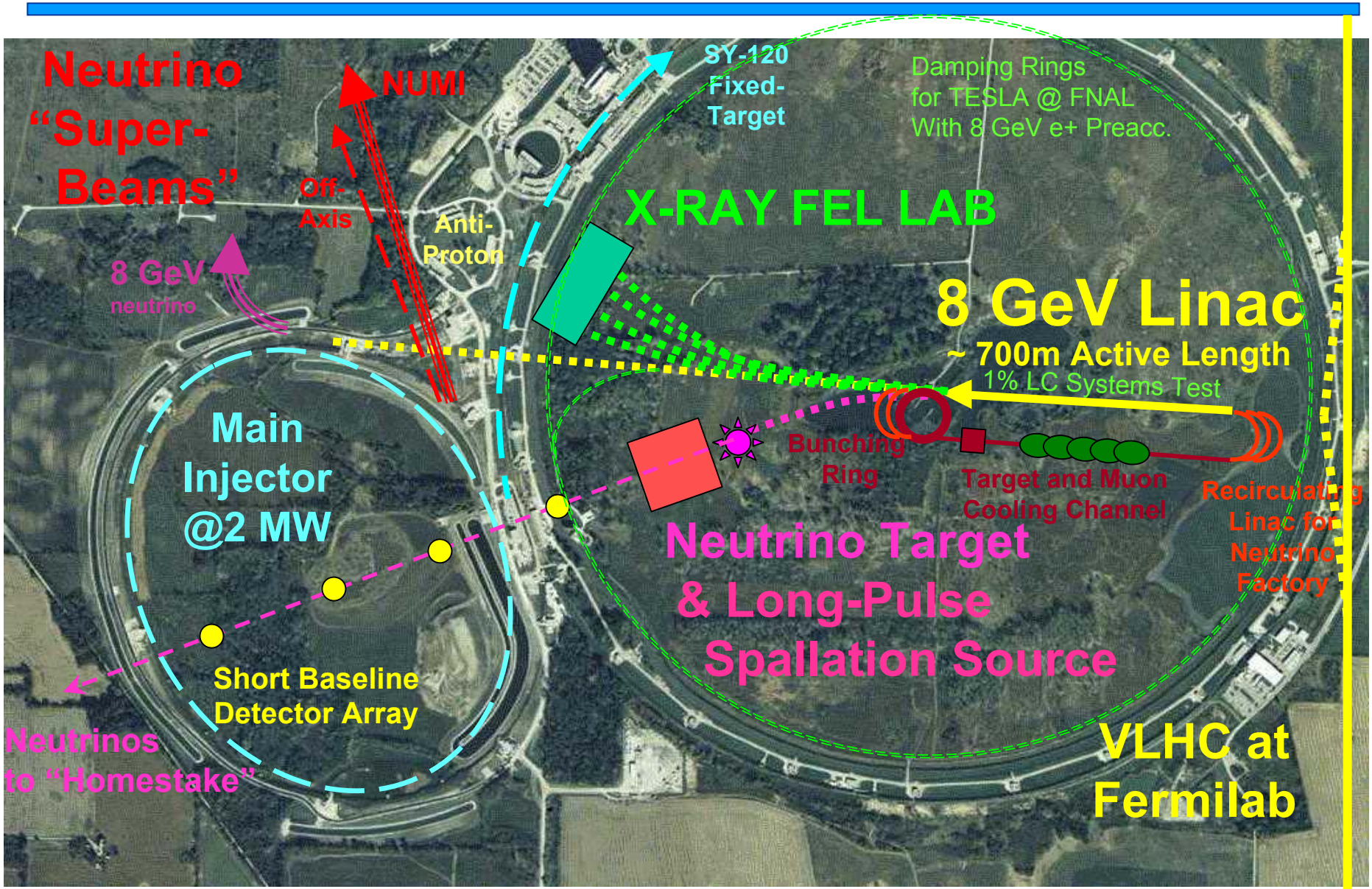


- **The linac and booster are "old" and will need to be replaced "soon"**
- **Desire for intense proton sources for long baseline neutrino physics**
- **High Level Parameters**
  - 0.5-2.0 MW beam power at 8 Gev
  - 2.0 MW beam power at 120 GeV
  - 6 x power of current Main Injector
- **Two Possible implementations**
  - 8 GeV Synchrotron
  - 8 GeV SCRF Linac
- **FLRPC: Linac is preferred**
  - Better performance
  - Flexibility
  - LC connection (TESLA technology)

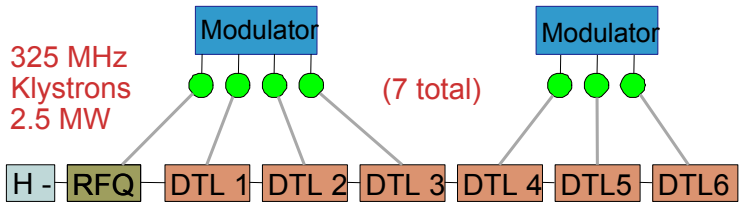
PD: 8 GeV SC Linac

- **Design concept originated with Bill Foster at FNAL**
  - Observation: $/ GeV for SCRF has fallen dramatically ➔Can consider a solution in which H- beam is accelerated to 8 GeV in a SC linac and injected directly into the Main Injector
- **Why an SCRF Linac looks attractive:**
  - Probably simpler to operate vs. two machines (i.e. linac + booster)
  - Produces very small emittances vs. a synchrotron (small halo & losses in MI)
  - Can delivers high beam power simultaneously at 8 & 120 GeV
  - Many components exist (fewer parts to design vs new booster synchrotron)
    - Use "TESLA" klystrons, modulators, and cavities/Cryo modules
    - Exploit development/infrastructure from RIA, SNS, JLAB, JPARC etc
  - Can be "staged" to limit initial costs & grow with neutrino program needs
- **Following the FLRPC recommendations FNAL started an effort to develop the SCRF linac design … (cost is an issue)**
- **Such a machine might have many different missions ➔ growth potential for the future if the Physics case exists…**

8 GeV Superconducting Linac



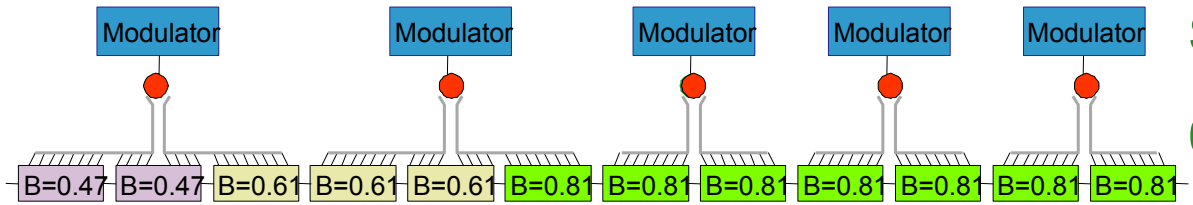
Baseline 2 MW 8 GeV LINAC



Warm Copper
Drift Tube Linac
325 MHz
0 - 87 MeV

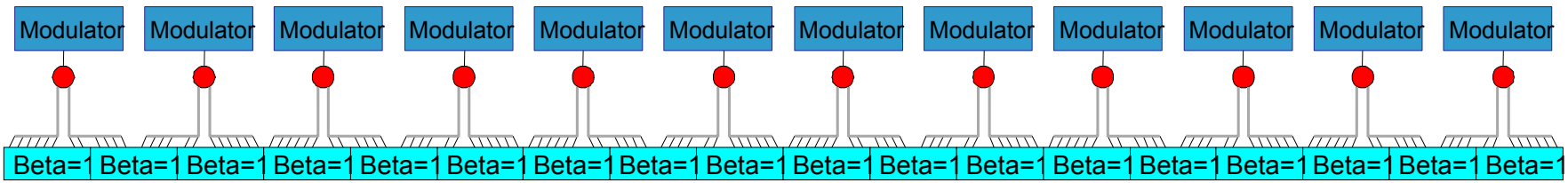
8 GeV 2 MW LINAC

36 Klystrons (2 types)
31 Modulators 10 MW ea.
7 Warm Linac Loads
48 Cryomodules
384 Superconducting Cavities



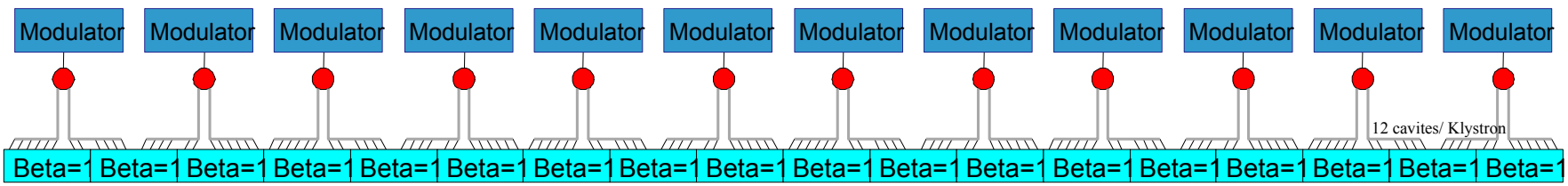
Squeezed Tesla cavities
1300 MHz
0.087 - 1.2 GeV

5 TESLA Klystrons, 10 MW each
96 cavites in 12 Cryomodules



"TESLA" LINAC 1300 MHz Beta=1

24 Klystrons
288 cavites in 36 Cryomodules

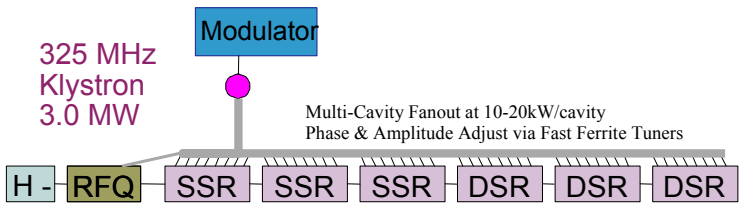


Linac Cost Optimizations & Options

- **Staging: Extend Klystron Fanout 12:1 → 36:1**
  - Drop beam current, extend pulse width
  - Drop rep. rate → avg. 8-GeV power 2 MW→ 0.5 MW
  - But… still delivers 2 MW from MI at 120 GeV with existing MI ramp rates
- **SCRF Front End? (using RIA Spoke Resonators)**
- **Assumed Gradients for TESLA cavities:**
  - Baseline 5 GeV linac by assuming TESLA 500 gradients,
  - Deliver 8 GeV linac by achieving TESLA 800 gradients.

384 Cavities → 240 cavities ; Linac Length: 650m → 400

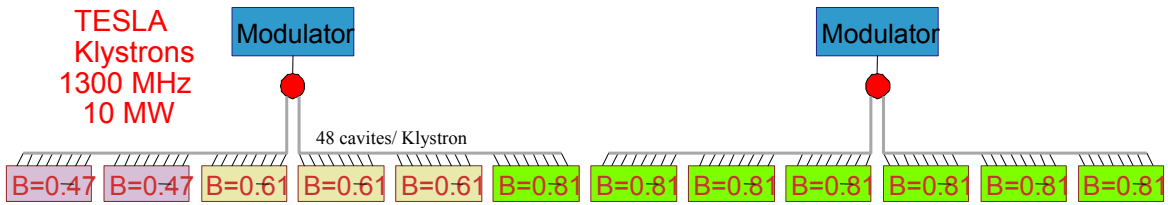
Staged:2 MW@120 GeV & .5 MW@8GeV,SCRF FE



"Pulsed RIA"
SCRF Linac
325 MHz
0 - 120 MeV

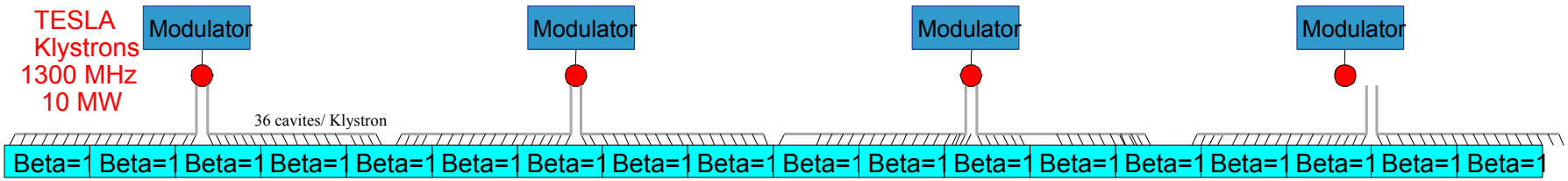
8 GeV 0.5 MW LINAC

- 11 Klystrons (2 types)
- 11 Modulators 20 MW ea.
- 1 Warm Linac Load
- 54 Cryomodules
- ~550 Superconducting Cavities



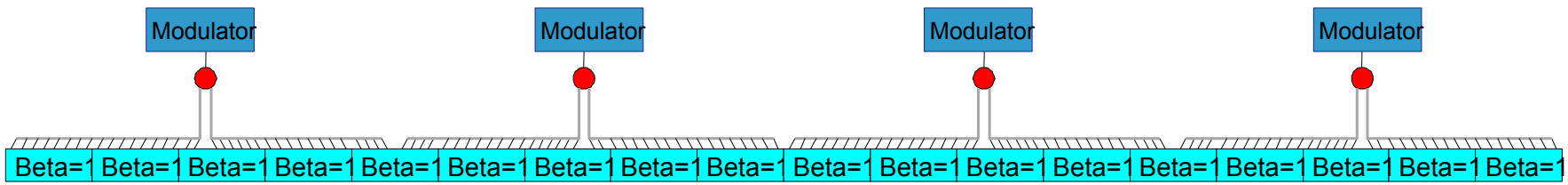
"Squeezed TESLA"
Superconducting Linac
1300 MHz 0.087 - 1.2 GeV

2 Klystrons
96 cavites in 12 Cryomodules

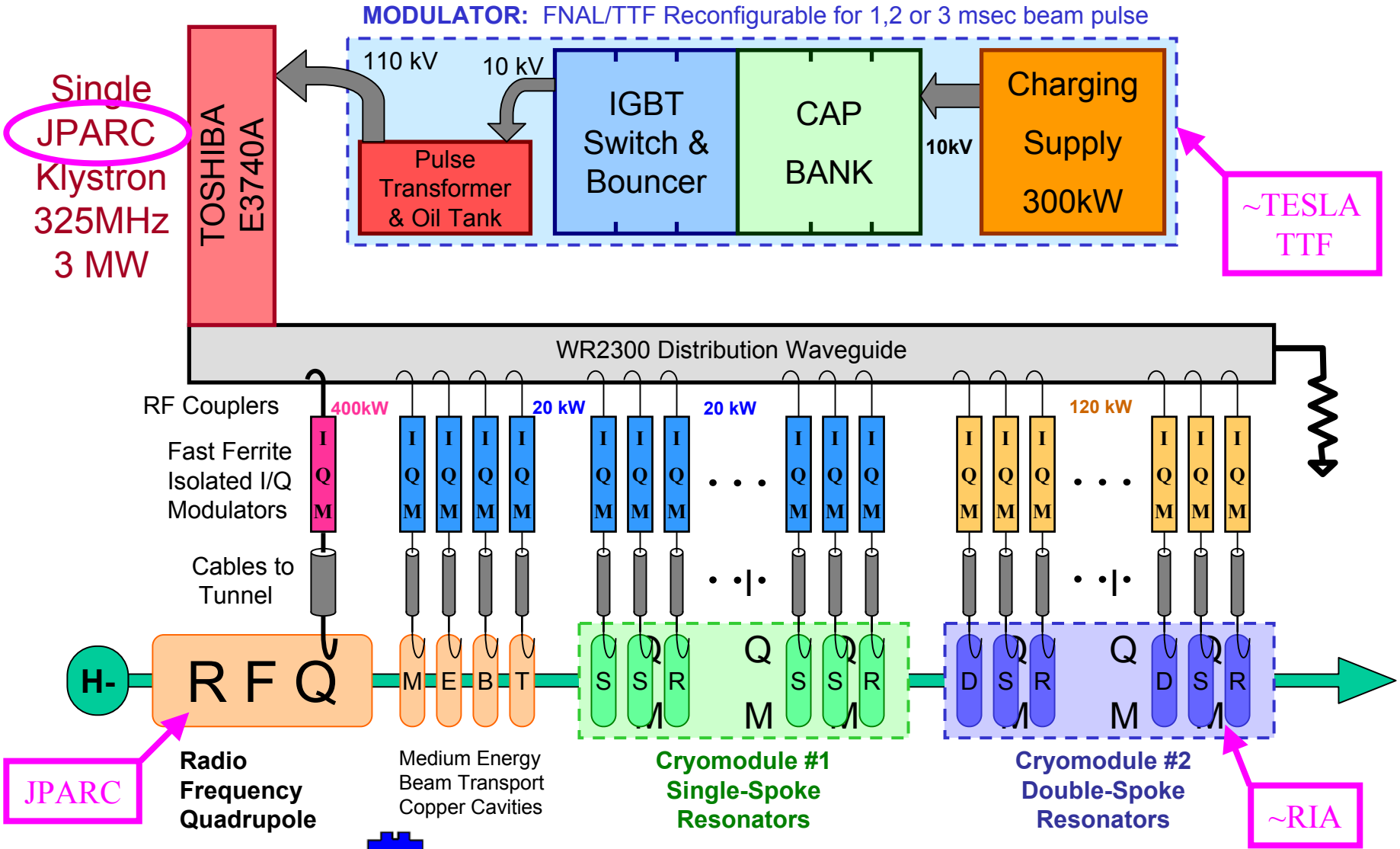


"TESLA" LINAC 1300 MHz Beta=1

8 Klystrons
288 cavites in 36 Cryomodules



325 MHz RF System



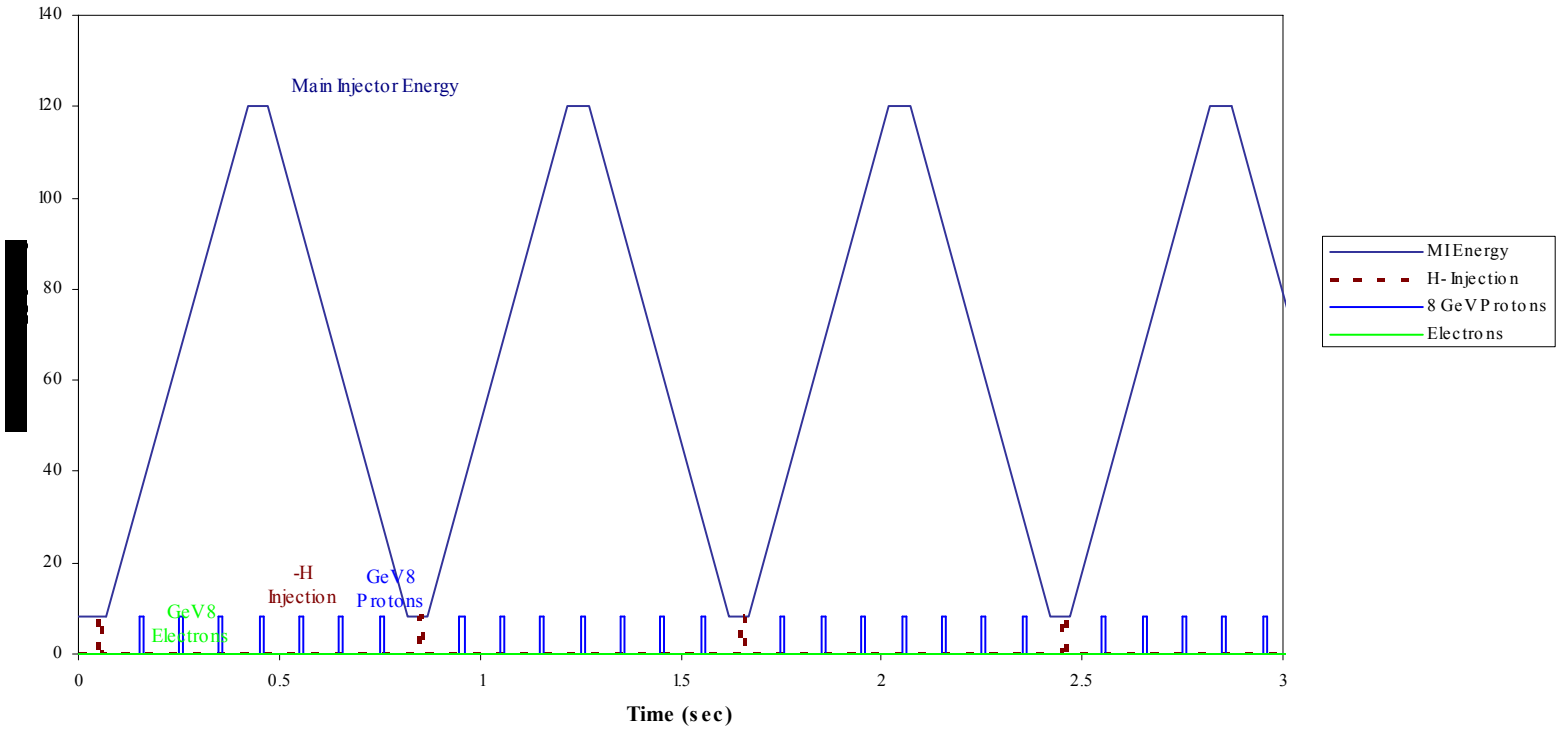
Main Injector Upgrades

- **For either choice of 8-GeV injector (synchrotron or SCRF linac) the beam in the Main injector will increase by a factor of ~ 5 from its design value of 3.0 E 13 protons per pulse to ~1.5 E 14**
- **The main injector beam power can also be increased by shortening the MI ramp time.**
  - Requires additional magnet power supplies
  - Could be done prior to a Proton Driver as a 1st step
- **More protons/cycle and/or faster ramp times ➔ more MI RF power required = $$$**
- **But shorter ramp time ➔ beam power goes up.**

Baseline Proton Driver & MI 0.8 sec cycle

Main Injector: 120 GeV, 1.15 Hz Cycle, 3.5 MW Beam Power
Linac Protons: 8 GeV, 10 Hz Cycle, 1.7 MW Beam Power

8 GeV Linac Cycles 1.5E14 per Pulse at 10Hz



Comparison of PD options

Parameters	Present Proton Source	Proton Driver synchrotron (PD2)	Proton Driver SCRF Linac only (2 MW baseline)	Proton Driver SCRF Linac and MI upgrade ?
Linac (Pulse Freq)	5 Hz	15 Hz	10 Hz	10 Hz
Kinetic energy (MeV)	400	600	8000	8000
Peak current (mA)	40	50	28	28
Pulse length (μs)	25	90	1000	1000
Booster (cycles at 15 Hz)				
Extraction kinetic energy (Gev)	8	8	-	-
Protons per cycle	5×10^{12}	2.5×10^{13}	-	-
Protons per hour	9×10^{16} (5 Hz)	1.4×10^{18}	-	-
8 GeV Beam Power (MW)	0.033 (5 Hz)	0.5	2	1.7
Main Injector				
Extraction Energy for NuMI (Ge	120	120	120	120
Protons per cycle	3×10^{13}	1.5×10^{14}	1.5×10^{14}	1.5×10^{14}
fill time (sec)	0.4 (5/15+0.1)	0.4 (5/15+0.1)	0.1	0.1
ramp time (sec)	1.47	1.13	1.4	0.7
cycle time (sec)	1.87	1.53	1.5	0.8
Protons per hour	5.8×10^{16}	3.5×10^{17}	3.5×10^{17}	6.7×10^{17}
Ave Beam Power (MW)	0.3	1.9	1.9	3.5

RDK unofficial

- **My conclusions: The SCRF Linac PD is more likely to deliver the desired performance, is more "flexible" machine than the synchrotron based PD, and has more "growth" potential**

Synergies with other Projects

- **Principal Mission: Proton superbeams for Neutrinos**
  - 8 GeV or 120 GeV from MI (NUMI/Off-axis)
  - Other Physics missions ? (We need to make the case)
- **Synergy with many other SCRF projects**
  - CBEAF upgrades, SNS, RIA, light sources, e-cooling @RHIC, eRHIC, etc
- **Strong connection with a Cold Technology LC**
  - Both require extensive SCRF infrastructure development
  - SCRF PD could be made to accelerate electrons
  - Proton Driver ~ 1% of a LC => improve the LC cost estimate
  - Can be used to study reliability and alignment issues
  - With a low emittance source ➔ LC beam studies
  - Possibly serve as part or all of a LC ETF
  - All of this can happen while the LC project is trying to organize complex international agreements and funding

FLRP PD Recommendations

- **We recommend that Fermilab prepare a case sufficient to achieve a statement of mission need (CD-0) for a 2 MW proton source (Proton Driver). We envision this project to be a coordinated combination of upgrades to existing machines and new construction.**
- **We recommend that Fermilab elaborate the physics case for a Proton Driver and develop the design for a superconducting linear accelerator to replace the existing Linac-Booster system. Fermilab should prepare project management documentation including cost & schedule estimates and a plan for the required R&D. Cost & schedule estimates for Proton Driver based on a new booster synchrotron and new linac should be produced for comparison. A Technical Design Report should be prepared for the chosen technology.**

PD Status and Plans

- **Charge by Director to Bill Foster, Steve Geer to prepare CD0 documentation by ~ Jan 05**
- **FLRPC meetings→ machine design & physics meetings**
  - AD,TD, PPD all have significant involvement
  - Meeting include:
    - PD Physics working groups
    - RF design and Beam dynamics
    - PD Cryogenics issues
    - Civil and Siting
    - Accelerator Physics Issues (e.g. H- stripping, etc.)
    - Improving Cost & Schedule estimates, etc.
  - Goal is to complete R&D to establish feasibility and to establish a baseline design in the next year
  - Enthusiasm! Lots of people joining the effort >50

PD: Status and Plans

- **Recent ITRP decision selected "cold" technology for the International Linear Collider. This will provide a HUGE boost for an SCRF linac based PD at FNAL**
- **Funding**
  - $ ~1 M of FNAL funding is earmarked for PD R&D in FY05
  - ITRP Decision ➔ Most of the $ 5 M of R&D funds earmarked for Linear Collider R&D will also serve to advance the Proton Driver
  - Overall, FY05 will see a factor of 2 increase in SCRF R&D spending at FNAL vs FY04
- **Plans are forming for a SCRF Module Test Facility to be built in Meson East, long lead time items like modulators are already being ordered. Recent SMTF collaboration meeting at Jefferson Lab. (Sept 29)**
- **Potentially SMTF can bring even more money into the mix (SLAC LC funds, NICADD, Japan, Italy ?)**

Timescale for a Proton Driver ?

- **Always hard to guess**
- **Technically limited schedule**
  - CD0 in 05
  - CD1 in 06 (preliminary: acquisition strategy, PEP, conceptual design report, project scope, baseline cost/schedule range, PMP, Hazard analysis, etc)
  - CD 2/3a in 07-08 (project baseline approved, approval to start construction)
- **Funds in FY09 ? Availability of funding from DOE may push this later**
- **Once funding is approved, typical projects of this scale (MI, SLAC B factory, KEK-B, SNS) have construction times of 4-5 years**
- **The timescale will also depend on how the Linear Collider plays out, over the next few years (e.g. PD = ETF ?)**
- **Its up to us to make the physics case that a Proton Driver is required and that it should go as fast as possible**
- **Making the PHYSICS CASE is crucial in all of this !**

CONCLUSIONS

- **It seems likely that a new intense proton source will be proposed for construction at FNAL in near future**
- **Similar in scope to the Main Injector Project (cost/schedule)**
- **A 8 GeV Synchrotron or a Superconducting Linac appear to be both technically possible. However the SCRF linac strongly preferred if it can be made affordable**
- **The FNAL management has requested that the 8 GeV linac design be developed including cost & schedule information**
- **A Technical Design will be developed (charge to Bill Foster)**
- **The Physics Case needs to be developed (charge to Steve Geer) and of course the goal of this workshop**
- **These will make it possible to submit a Proton Driver project to the DOE for approval and funding**